

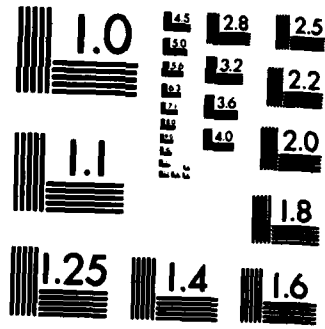
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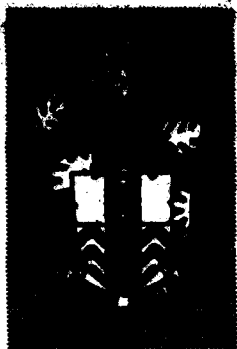


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**RSRE  
MEMORANDUM No. 3691**

**ROYAL SIGNALS & RADAR  
ESTABLISHMENT**

**HEAVY DUTY PRECISION PAN AND TILT HEAD**

**Authors: D Bagshaw, M R Brown, F Mansfield  
and J D Roberts**

**PROCUREMENT EXECUTIVE,  
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## ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 3691

Title: HEAVY DUTY PRECISION PAN AND TILT HEAD

Authors: D Bagshaw, M R Brown, F Mansfield and  
J D Roberts

Date: April 1984

### SUMMARY

This Memorandum describes the mechanical and electronic design of a heavy duty precision pan and tilt head driven by stepper motors and controlled by digital servos in both axes. The design aims were to produce a head able to carry a load of 150 kg, that could be positioned to 0.1 mR in either axis, able to slew at 0.2 R/s and that could be remotely controlled by either position or velocity demands. The testing of the engineered head for repeatability and frequency response is described and the results compared with the design requirements. Some suggestions are made as to how the performance of the head can be improved.

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RSRE MEMORANDUM 3691

HEAVY DUTY PRECISION PAN AND TILT HEAD

D Bagshaw, M R Brown, F Mansfield and J D Roberts

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1 INTRODUCTION

In the laboratory testing or field trial assessment of electro-optic surveillance and weapon aiming equipment there is normally a requirement to point a collection of comounted equipment consisting of such as lasers, thermal sights and television cameras, to look at the same target for simultaneous data acquisition. The pan and tilt head required for this purpose has to be large enough to carry the equipment to be mounted, precise enough to point at the required area of the target, robust and rigid enough to maintain the collimation between each piece of equipment and accurate enough for the head to be controlled remotely in an open loop situation.

This memorandum describes the mechanical and electronic design of an heavy duty precision pan and tilt head driven by stepper motors and controlled by digital servos in both axes. The design aims were to produce a head able to carry a load of 150 kg, that could be positioned to 0.1 mR in either axis, able to slew at 0.2 R/s and that could be positioned remotely controlled by either position or velocity demands. The testing of the engineered head for

repeatability and frequency response is described and the results compared with the design requirements. Some suggestions are made as to how the performance of the head can be improved.

## 2 MECHANICAL DESIGN

The requirement that the head be a general purpose system capable of adaption to carry a wide variety of equipment dictates an open frame structure mounted within a yoke, with additional platforms top and bottom of the frame together with side brackets (Figure 1). The open frame made from channel aluminium alloy has an open area within the frame of 60 cm by 60 cm. The yoke structure made as a casting in aluminium alloy is mounted on a chassis base platform of area 115 cm by 100 cm and depth 37 cm. The base platform is made of channel aluminium alloy and is fitted with wheels and jacks to give mobility and stable mounting when stationary. The elevation drive to the open frame is incorporated on the trunions at the head of the yoke structure while the azimuth drive to the yoke structure is fitted at the interface of the yoke to the base platform. Preloaded roller bearings are used in preference to plain bearings to minimise any stick or slip problems whilst maintaining system rigidity. A special cross roller bearing is used for the azimuth movement bearing.

The detailed mechanical design of the frame and yoke structures was determined by the requirement that with a loading of 150 kg of optical and electro-optical equipment the collimation between widely separated pieces of equipment should be maintained to better than 0.1 mR. This requirement dictates that the frame structure should not flex by more than 25  $\mu$ m and that the trunion line should not be displaced by more than 60  $\mu$ m in both planes.

The gearboxes between the drive motors and the head were chosen to be single stage worm/wheel gears which had the additional benefit that they were self locking thus eliminating the need for a braking system. The pointing accuracy dictated that for an 80 cm diameter main gearwheel that the backlash between the wheel and worm would have to be reduced to less than 0.02 mm. This requirement dictated the use of Class A gear teeth. A flywheel was mounted on the drive motor shaft to limit the acceleration or deceleration of the motor and so reduce the loading on the gear teeth in the event of a drive circuit failure. The combined inertia of the drive motor and flywheel was designed to be a substantial part of the head inertia as reflected through the gearbox. A simple friction clutch was fitted on both axes to prevent damage to the gearboxes during transportation. Specially designed gearboxes of ratio 2:1 and 4:1 were incorporated between the drive shaft and encoders in azimuth and elevation respectively to match the encoder resolution of 0.1 mR.

The head was designed to move 90° in azimuth and +60° to -30° in elevation with hand drives as a fallback option in case of electrical failure. The weight of the unloaded head is 250 kg and limited environmental protection is provided for field trial situations.

## 3 MOTOR DRIVE DESIGN

One essential requirement on the design of a motor drive system is that it must be stable and for this reason a digital control and stepper motor drive system was adopted. Analogue systems were rejected as they have a tendency to

drift unless elaborate precautions are taken. The stepper motor has a torque-speed characteristic that can be divided into three regions; the first region is the stopped region where the maximum torque is developed. This torque is the holding torque and it will act as a brake on the load. The second region is the stepping region where the motor will stop and start following the pulse input, within the specified load torque. This region is the one normally used for control and positioning the head. The third region is the slewing region which can only be used after acceleration through the second region. This region allows high speed running with limited acceleration and the torque falls to zero at the higher speeds. The benefits that a stepper motor offers over a dc servo motor are that it does not require the separate brake needed by the dc motor design during the first two regions and that it has a more precise speed control during the third region. The two main disadvantages of the stepper motor are that it has a higher noise level than dc motors and that it needs to have a controlled acceleration through the stepping region.

The requirement on the head is that it should have a pointing accuracy and repeatability of 0.1 mR in both axes. The position of the head and the demanded angular position are monitored by absolute position encoders. In order to have a unique code for each 0.1 mR step in  $2\pi$  radians requires a 16 bit binary word. Generally available stepping motors have 200 steps in one revolution but it is possible to increase this to 400 steps with more complicated drive circuitry. In order to ensure stability it was decided to make the motor steps less than the encoder steps and this means each step of the stepping motor should be equivalent to an 0.05 mR movement of the head. This dictates that the gear ratio of the worm/wheel gearboxes should be 328:1. The actual choice of motor is determined by the requirements for the head to slew at 0.2 R/s and the torque to be adequate to move the head, with estimated inertia of 50 kg.m<sup>2</sup> at an acceleration of 0.2 R/s<sup>2</sup>. As friction within the worm/wheel gearboxes is difficult to calculate the torque requirement of the stepper motor was increased by a factor x 3 over that required for acceleration alone. These considerations resulted in the choice of a stepper motor with speed 548 rpm and a torque of 0.1 kg.m.

As stated to cover 360° requires a 16 bit binary word but, in the event because the angular range requirements were only  $\pm 90^\circ$  in azimuth and  $+60^\circ$  to  $-30^\circ$  in elevation 15 bit encoders were used to reduce cost.

#### 4 CONTROL CIRCUITRY

The block diagrams for the electronic control circuitry are given in Figure 2, where Figure 2a gives the position control circuitry while Figure 2b gives the velocity control circuitry. The circuits are duplicated for movements in the azimuth and elevation directions.

##### 4.1 POSITION CONTROL CIRCUIT

The outputs from the head position encoder and the demanded position encoder are brought together at the subtractor. The function of the subtractor and rectifier in combination is to set the stepping rate and identify the sense of rotation of the stepping motor. The two 15 bit words are subtracted by the "two's complement" method and the 16th bit or overflow is used to determine the sign of the required movement. The selective digital rectifier is used to complement the difference when the overflow bit is set to one direction. An example of this method using 4 bit words would be:



demand	+9	1001	demand	+7	0111
head	+7	0111	head	+9	1001
subtract		<u>1,0001</u>	subtract		<u>0,1101</u>
			rectify		0010

In the left hand case, with overflow set to 1, rectification is not needed and the difference is passed forward. In the right hand case the rotation required is in the opposite sense so rectification is needed before the difference is passed forward. This example also shows the stability introduced by having the motor step increments finer than the encoder increments.

The rectified difference passed forward is used to control the state of two selection circuits. The most significant 9 bits of the difference are examined at the comparator and if all the bits are set to 0 state then the AND gate A is inhibited and AND gate B is enabled. This corresponds to a small difference between head and demanded positions and the output to the motor drive  $f_{OUT}$  will be determined by the binary rate multiplier (BRM). The BRM reduces the frequency of a pulse train  $f_{IN}$  by the ratio

$$f_{OUT} = M f_{IN} / 64$$

$$\text{where } M = A2^0 + B2^1 + C2^2 + D2^3 + E2^4 + F2^5$$

and A to F are the digital conditions of the least significant 6 bits of the difference, so the ratio will vary between 0 and 63  $f_{IN}/64$  according to the magnitude of the difference. The selection of BRM corresponds to the second region of operation referred to in section 3. If the difference at the comparator is so gross that any of the most significant 9 bits are in the 1 state then the AND gate A is enabled and AND gate B is inhibited. This will allow the input stepping frequency  $f_{IN}$  to pass unattenuated through gates A and C to the motor. This circuit selection corresponds to the third region of operation referred to in section 3. So if the demanded position is suddenly increased the control circuitry responds by accelerating through the selection of BRM into the constant speed region, the maximum velocity being set by the stepping rate of the motor. This method of positional control gives precise control at all times in the movement cycle.

#### 4.2 VELOCITY CONTROL CIRCUIT

The velocity control circuit is independent of the position control circuit and is essentially analogue with a voltage to frequency converter to generate the motor drive pulses. The velocity demand can be accepted from a wide range of sources such as joystick controllers or even automatic lock-follow systems. The input voltage is limited and passed through a lowpass filter to ensure that the demanded pulse rate and the rate of change of the pulse rate stays within the range that the stepper motor can accept. The direction of movement of the head is determined by whether the input voltage is above or below earth. The output pulse rate is linear with voltage above threshold. This threshold or dead

band eliminates any drift when for example the joystick is at rest and there is no velocity demand.

## 5 PERFORMANCE TESTING

The two performance requirements tested were the repeatability of the position control and the frequency response of the velocity control.

### 5.1 REPEATABILITY

The ability of the head to return to the same position given the same demand position input was tested in both axes and from both directions. The "same position" was measured by mounting a standard daylight vidicon fitted with a 1200 mm focal length lens on to the head, and viewing a marker at a distance in the field of view. The CCIR display had a field of view of nominally 6 mR and a resolution that enabled measurements to be made to 50 R of the marker position. These series of measurements showed that the repeatability in position for a given demand in either axis was better than 0.1 mR, the design requirement.

### 5.2 FREQUENCY RESPONSE

A convenient method for measuring the maximum velocity and acceleration of the head is to feed the velocity drive circuit with a sine wave of varying amplitude at a series of preset frequencies. Under this condition the amplitude at which the head stalls is a measure of the maximum velocity possible for the accelerations imposed by the input sine wave. It is possible to calculate the corresponding acceleration from this measure of velocity. Figure 3 shows the results obtained from the head in azimuth under two conditions: curves 1 and 2 relate to the measurements made with no limiter or lowpass filter in the velocity control circuit, so as such represent the maximum velocity and acceleration that can be achieved by the head, while curves 3 and 4 relate to the measurements made with limiter in and a lowpass filter of time-constant 0.1 s, so as to lower the demands on velocity and acceleration that can be made.

These results show that for the unlimited case in azimuth with a 50 kg load the head can achieve a maximum velocity of 0.3 R/s and an acceleration of 1.6 R/s<sup>2</sup>. For the limited case, which would tend to be normal operation, the maximum velocity is 0.1 R/s and the acceleration is set to 1 R/s<sup>2</sup>. These results show that the head can achieve a slew rate of 0.2 R/s, the design requirement, albeit with a reduced load.

## 6 CONCLUSIONS

This engineering build programme has established that a heavy duty pan and tilt head can be designed to meet the specifications required for a general purpose head for electro-optic surveillance and weapon aiming experiments in both the laboratory and field.

The design of the head, while it met the required performance is capable of being improved to give increased performance. There are four areas where the design can be changed:

a Stepper motors can be driven at 1000 steps each revolution and this will offer the potential for increased positional accuracy better than 0.05 mR. To exploit this improvement the worm/wheel gear design will need to be improved to reduce backlash.

b The resolution of the encoders can be increased to 16 bit resolution and this will permit the removal of the gearbox between shaft and encoder and a rotation over 360° in the azimuth plane unambiguously.

c Higher torque stepper motors can be obtained which will allow shorter time constants in the velocity control circuit which will give an improved head response time.

d. The drive to the azimuth can be improved by the use of two worm/wheel gears which will reduce the tooth loading and so give an increase in life of the head.

## 7 ACKNOWLEDGEMENTS

The authors wish to acknowledge the design ability and engineering skill shown by the Engineering Services Departments at RSRE.

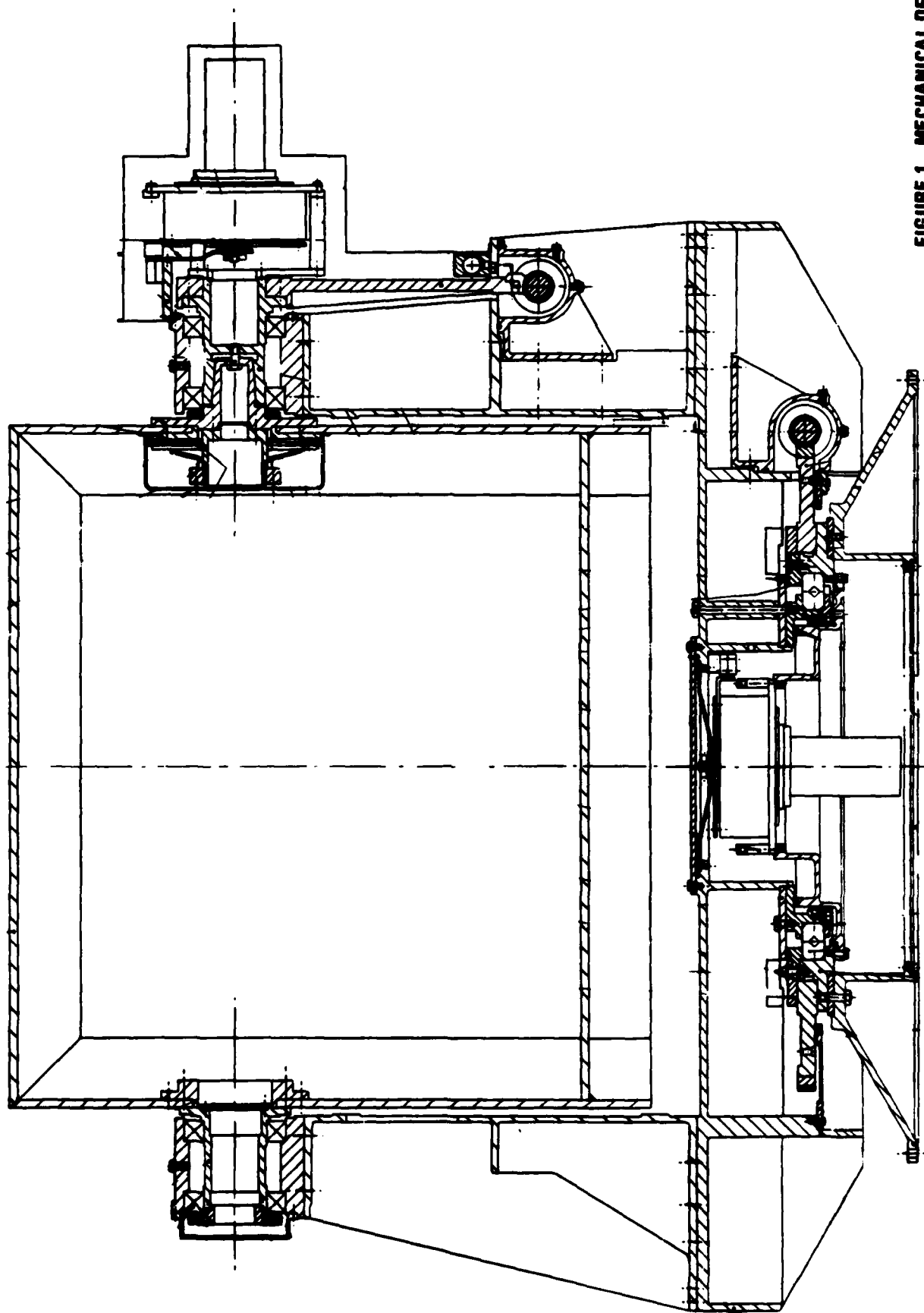


FIGURE 1 MECHANICAL DESIGN

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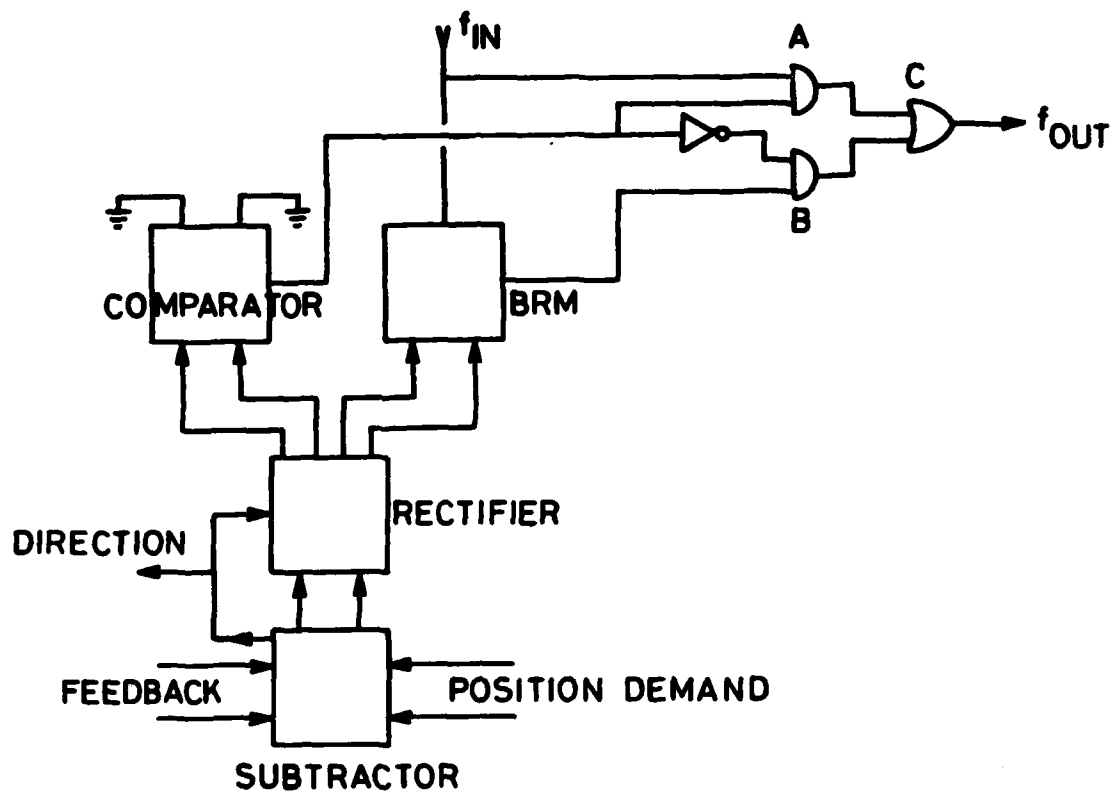


FIG. 2a POSITION CONTROL

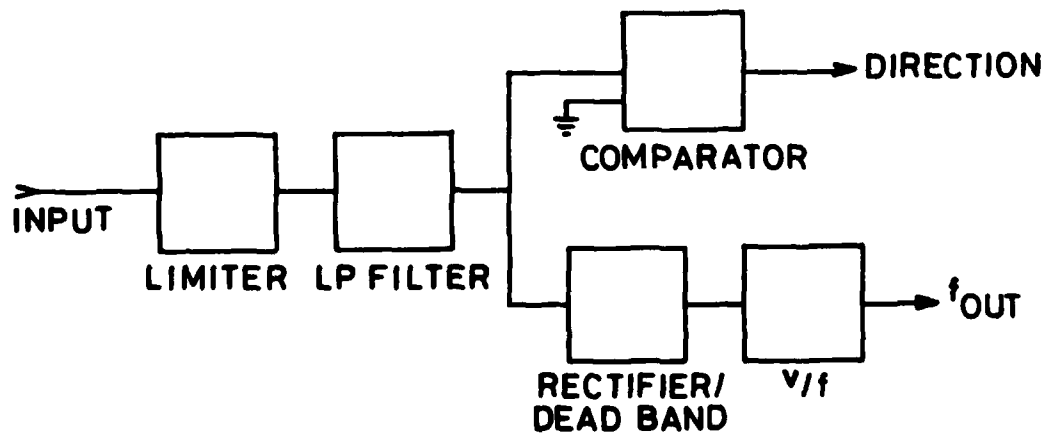
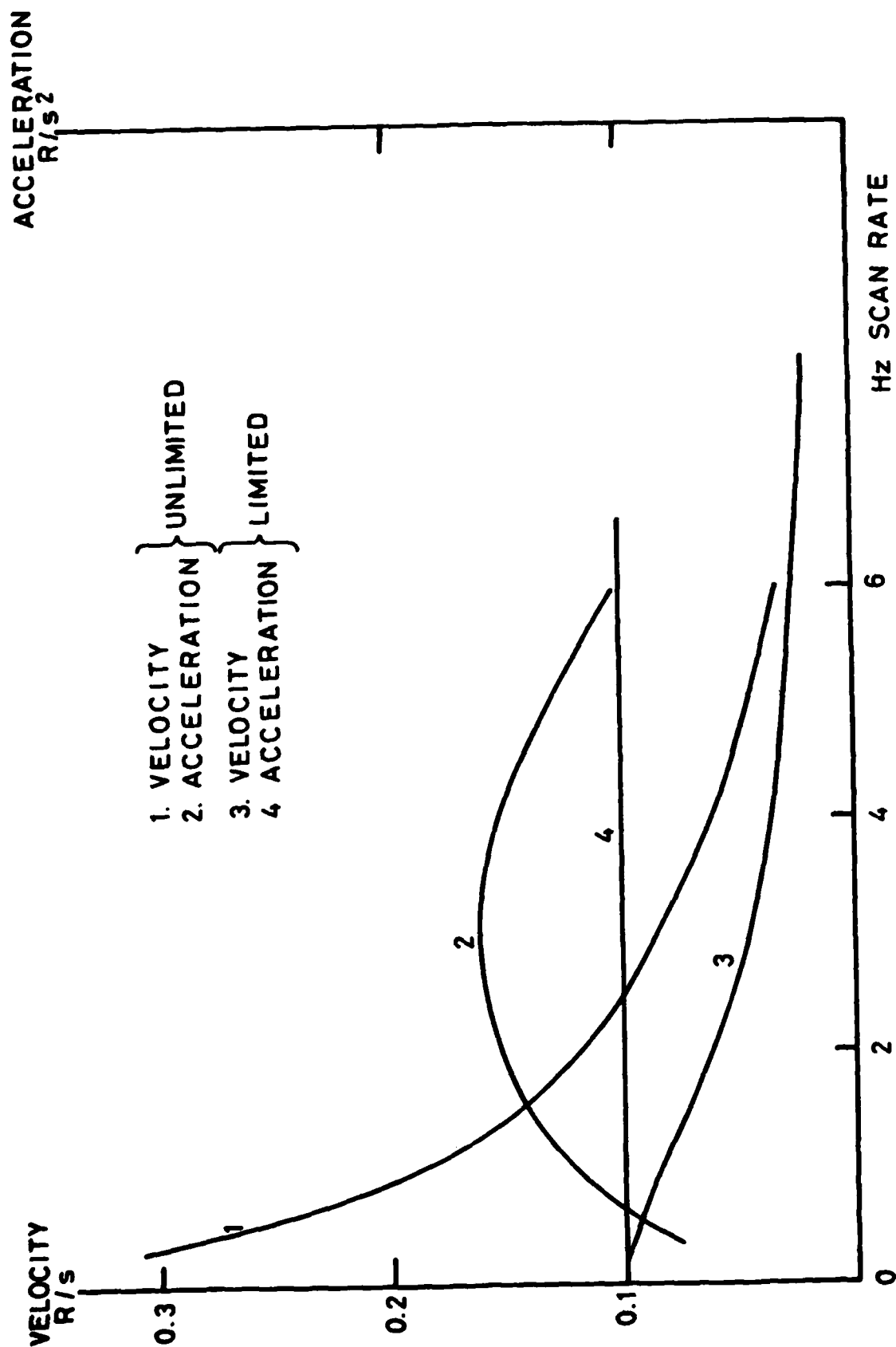


FIG. 2b VELOCITY CONTROL

FIG. 2 CONTROL CIRCUITRY



**FIG. 3 FREQUENCY RESPONSE**

## DOCUMENT CONTROL SHEET

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